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Title: Quarkonia Production in p+p, d+Au and A+A from PHENIX

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Quarkonia Production in $p+p$, $d+Au$ and $A+A$ from PHENIX

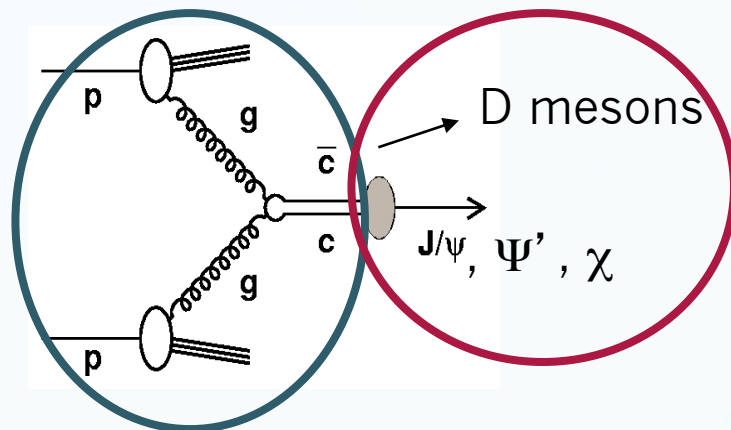
Melynda Brooks
Los Alamos National Laboratory
For the PHENIX Collaboration

Heavy Flavor Production

Factorize calculations:

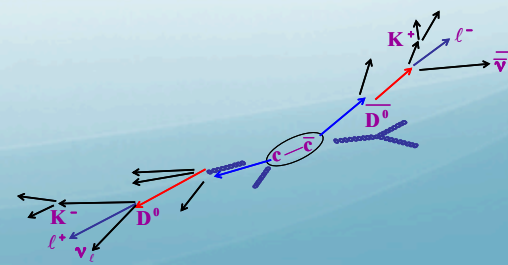
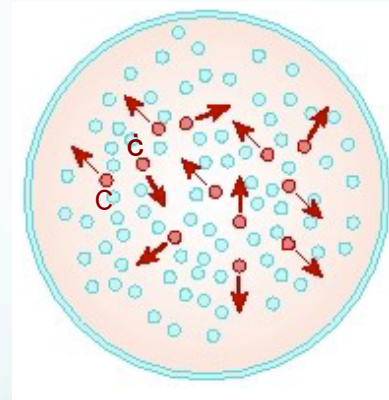
- pQCD to calculate $c\bar{c}$ production
- $c\bar{c}$ propagation and hadronization

Note: much of J/ψ production comes from feed-down from higher resonances, B



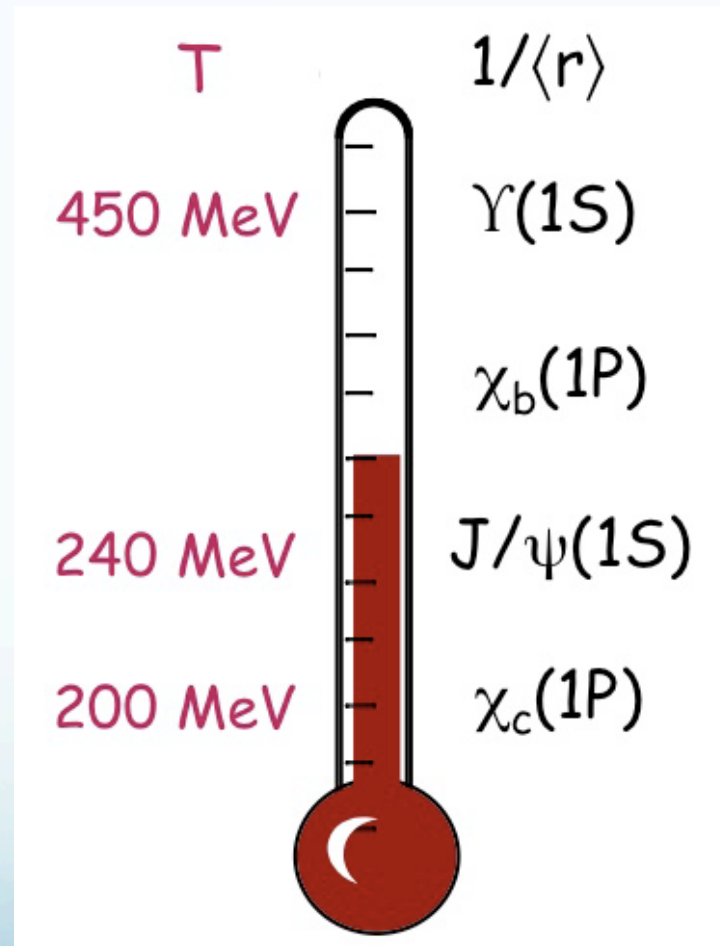
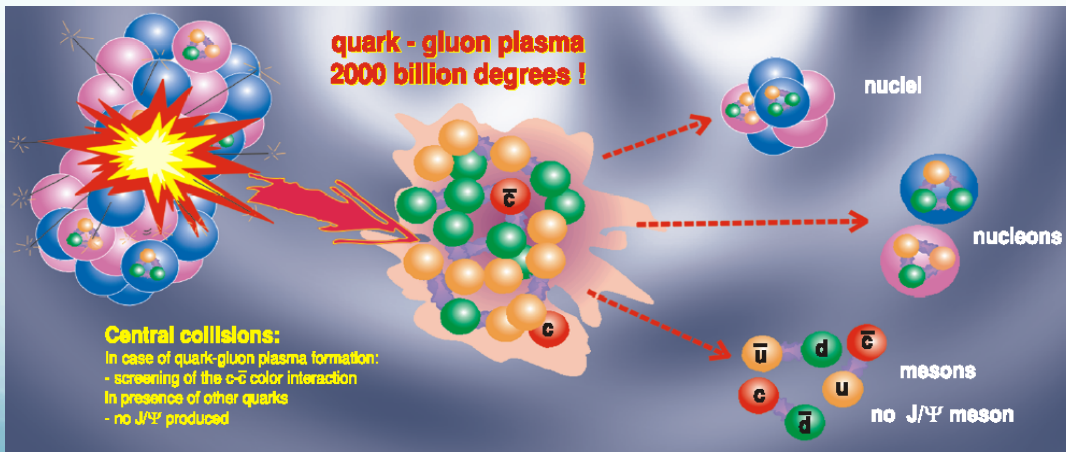
Possible Modifications beyond p+p production extrapolation:

- Parton Distribution Functions modified in nucleus?
 - Energy loss of partons traversing nucleus
 - Cronin modification of p_T spectra
 - Breakup of charmonium before exiting nucleus
 - Energy loss of partons traversing QGP
 - Debye screening of charmonia by QGP
 - If enough $c\bar{c}$, can have charmonium production through coalescence
- Note heavy flavor kinematics differences



Upsilon

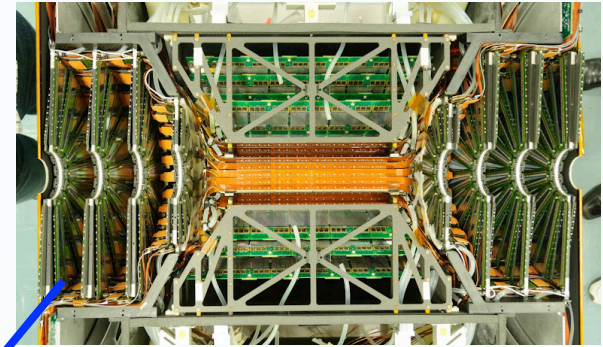
- Charmonia plus upsilon states covers large range of binding energies which can give indication of whether screening is occurring or not



The PHENIX Detector

Central Arms:

- $\Upsilon, J/\psi, \psi' \rightarrow e^+e^-$
- $D \rightarrow X+e$



Adding FVTX:

- $\psi' \rightarrow \mu^+\mu^-$
- D, B

Au

$x \approx 5 \times 10^{-3}$
Shadowing region

Muon Arms:

- $\Upsilon, J/\psi \rightarrow \mu^+\mu^-$
- $D \rightarrow X+\mu$

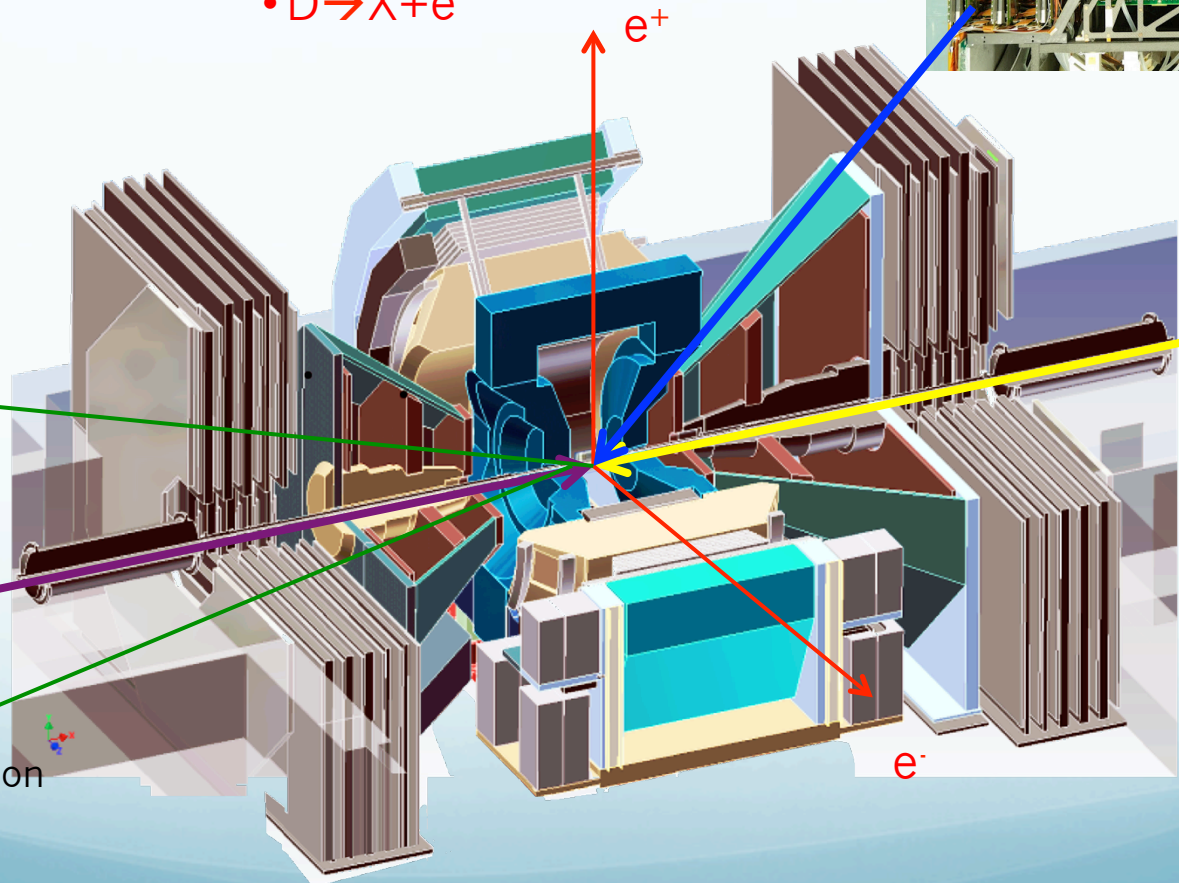
μ^+

d, Cu, Au

μ^-

e^-

$x \approx 8 \times 10^{-2}$
Anti-shadowing region



PHENIX Data Sets

p+p (200 and 510 GeV)

- J/ψ , ψ' , Y at central and forward rapidities

d+Au (200 GeV)

- J/ψ , ψ' , χ_c , Y at central rapidity
- J/ψ , Y at forward/backward rapidities

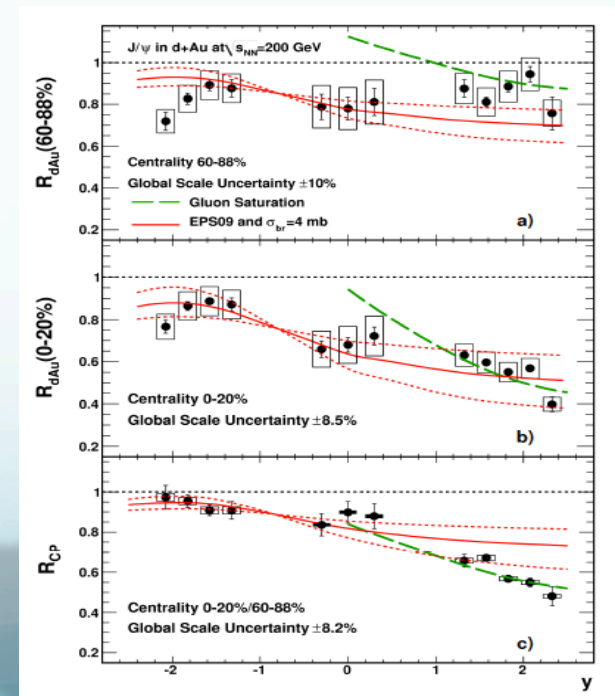
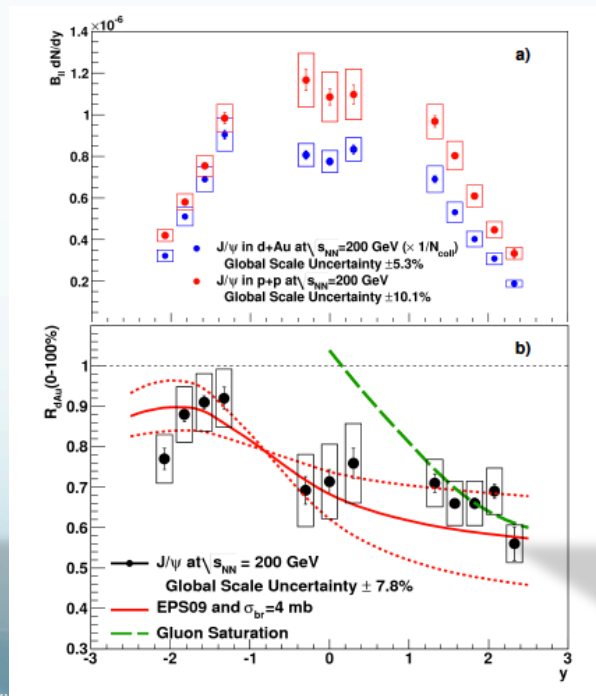
Cu+Cu, Cu+Au, (200 GeV), Au+Au (39, 62, 200 GeV)

- CuCu J/ψ R_{AA} at forward/backward rapidities
- CuAu J/ψ R_{AA} at forward/backward rapidities
- AuAu J/ψ R_{AA} at central and forward rapidities
- AuAu J/ψ R_{cp} at 39, 62, 200 GeV, forward rapidities
- CuAu, AuAu ψ' at forward rapidities analysis underway
- AuAu Y at central rapidity

J/ψ in d+Au Collisions: Cold Nuclear Matter Effects

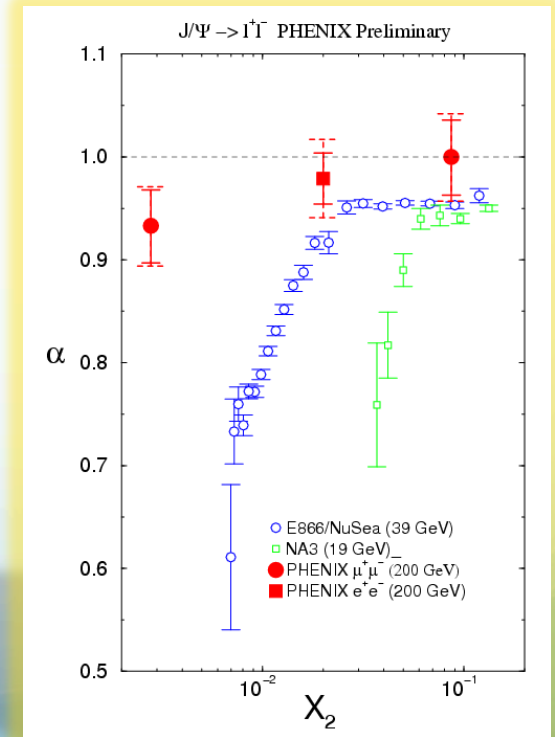
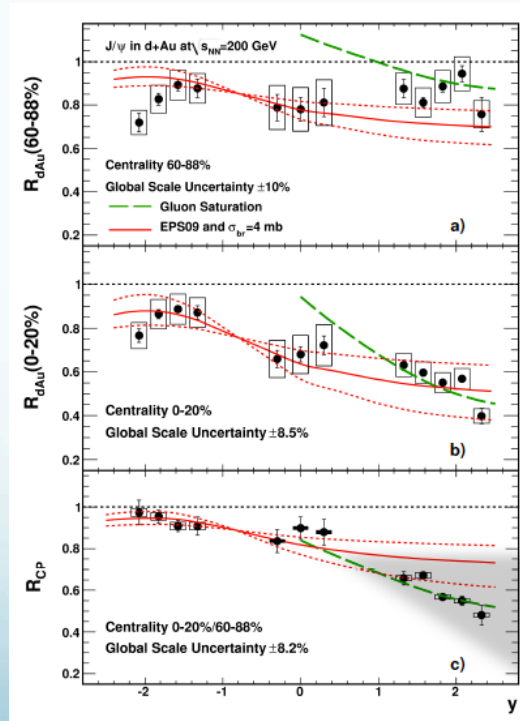
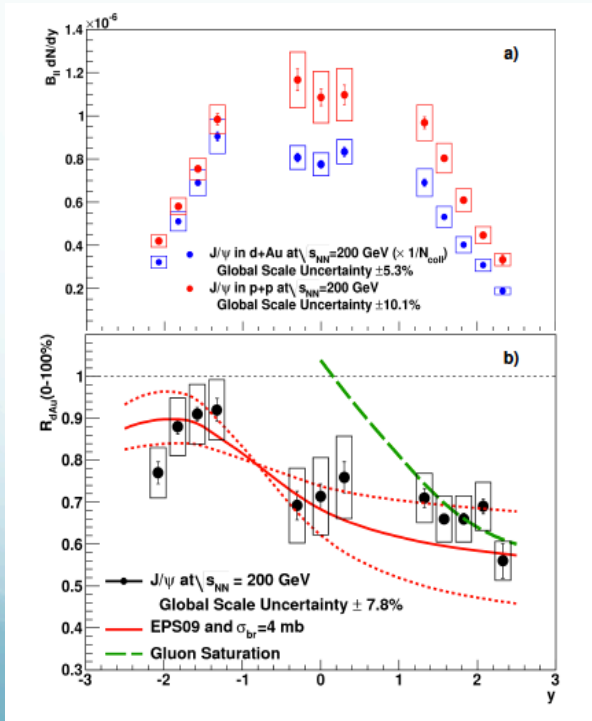
- In d+Au collisions, rapidity-dependent R_{dA}
- Forward rapidity shows more suppression than central/backward rapidities. Centrality-dependent.
- Possible explanations: gluon shadowing, nuclear breakup, energy loss

$$R_{dA} = \frac{dN/dy_{dAu}}{dN/dy_{pp} * N_{coll}}$$



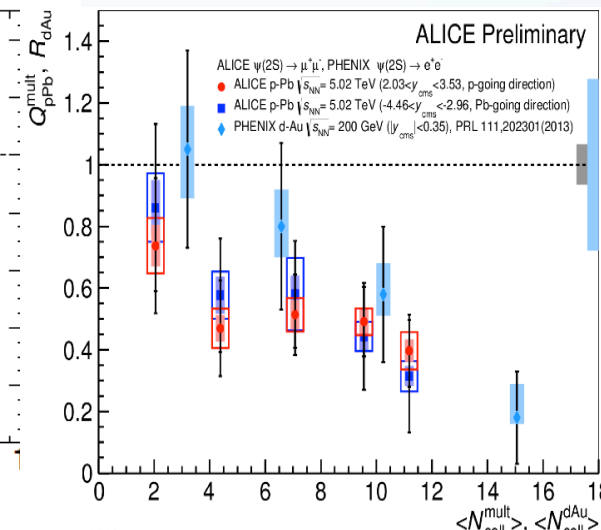
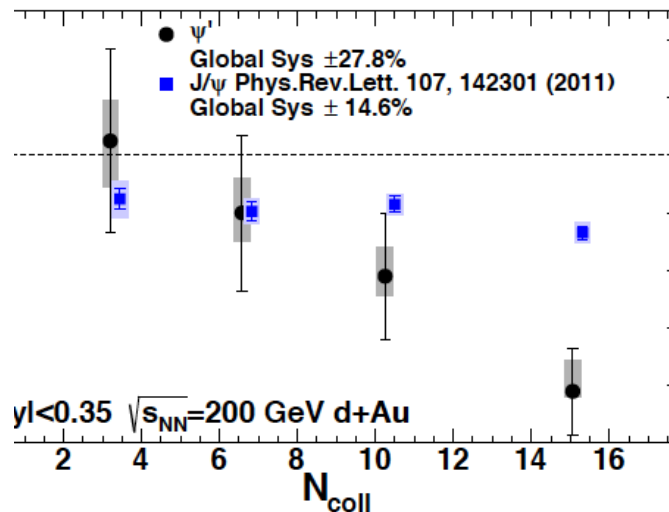
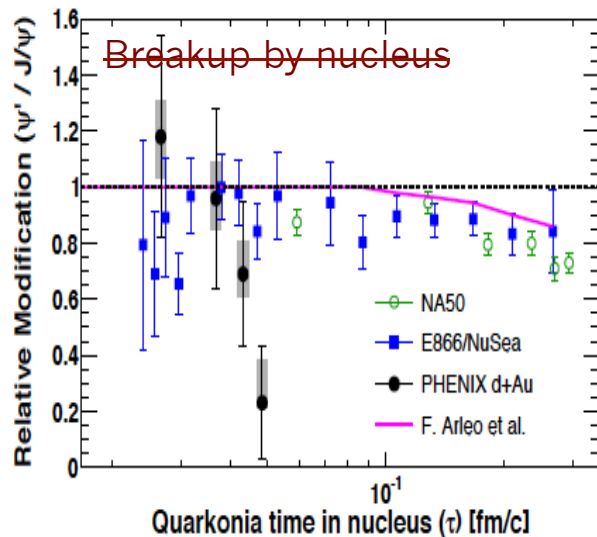
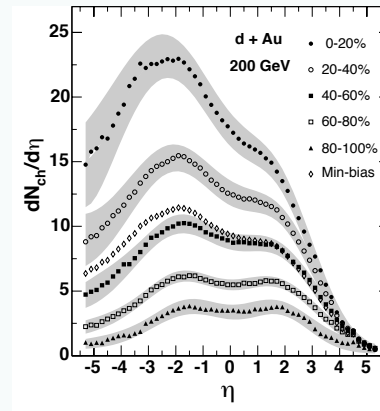
However,

- We do not see x_2 scaling, which would be indicative of gluon shadowing
- Initial-state energy loss and final-state effects?



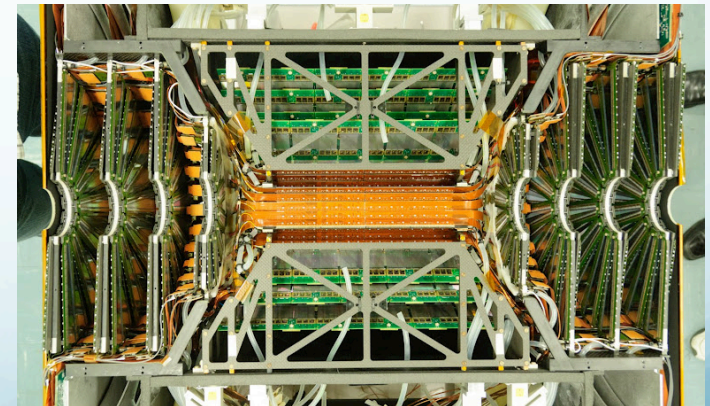
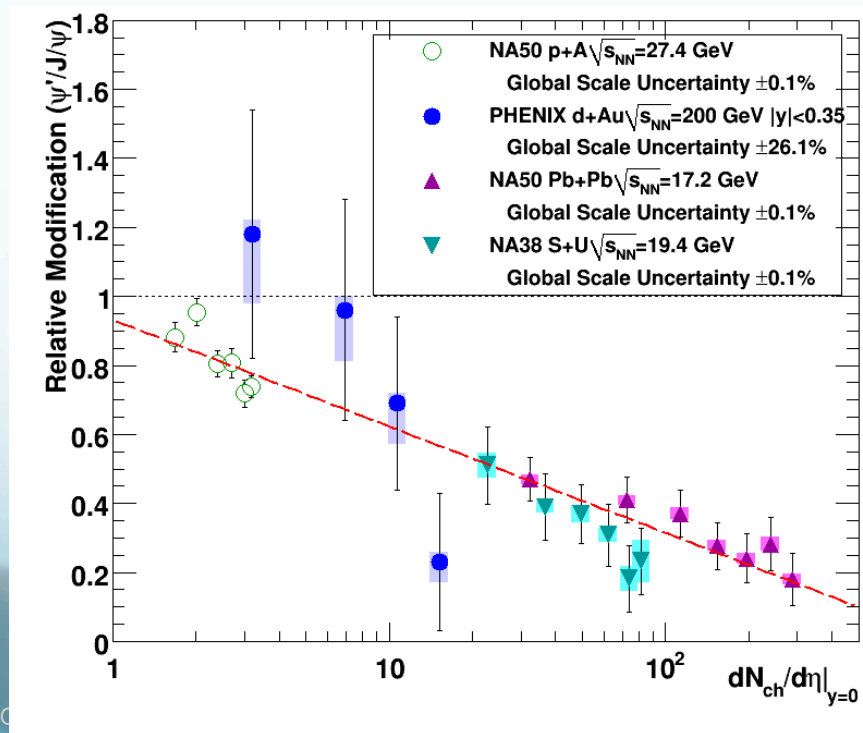
Comparing CNM for J/ψ , ψ'

- PHENIX: ψ' suppressed more than J/ψ at central rapidity, in d+Au. Time spent in nucleus (breakup) does not hold as explanation for PHENIX data.
- Universal trend with $dN_{ch}/d\eta$ for several systems, up to 200 GeV
- Alice p-Pb data also seems consistent with this trend



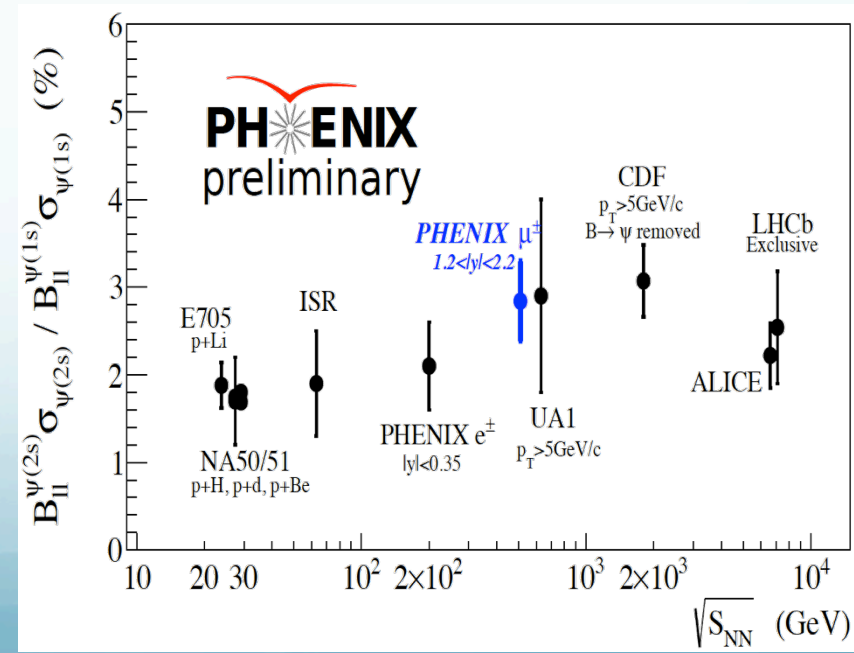
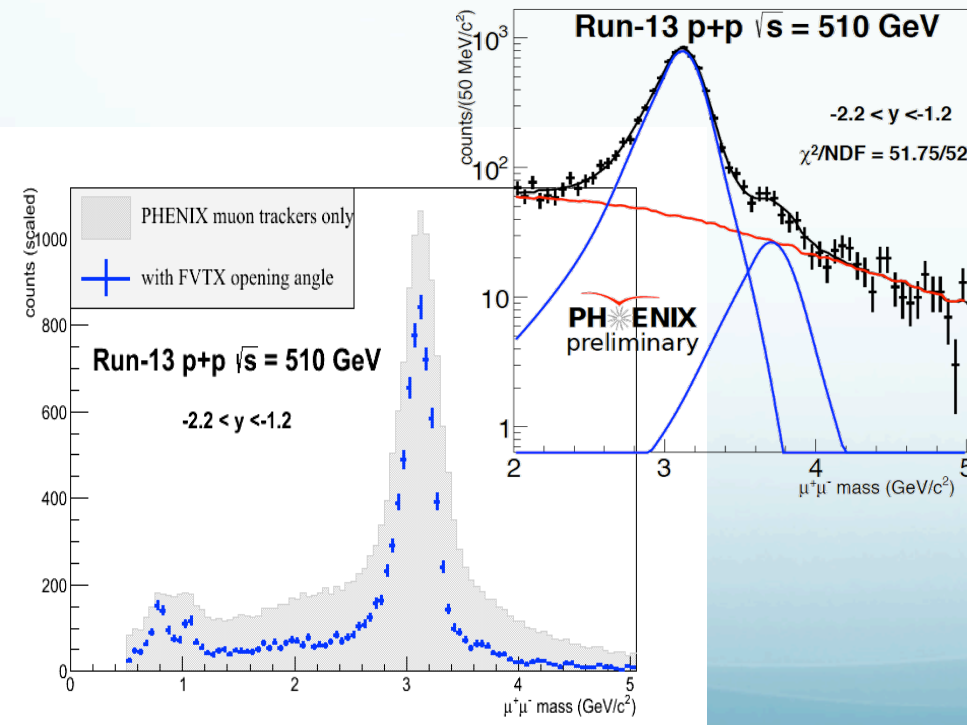
Comparing CNM for J/ψ , ψ'

- Would like to more fully explore the trend with $dN_{ch}/d\eta$, but current data are limited (see below)
- New p+A and heavy ion data from forward rapidity will expand our coverage at RHIC
- Vertex Detectors allow us to explore trend versus event multiplicity



$J/\psi:\psi'$ at Forward Rapidity

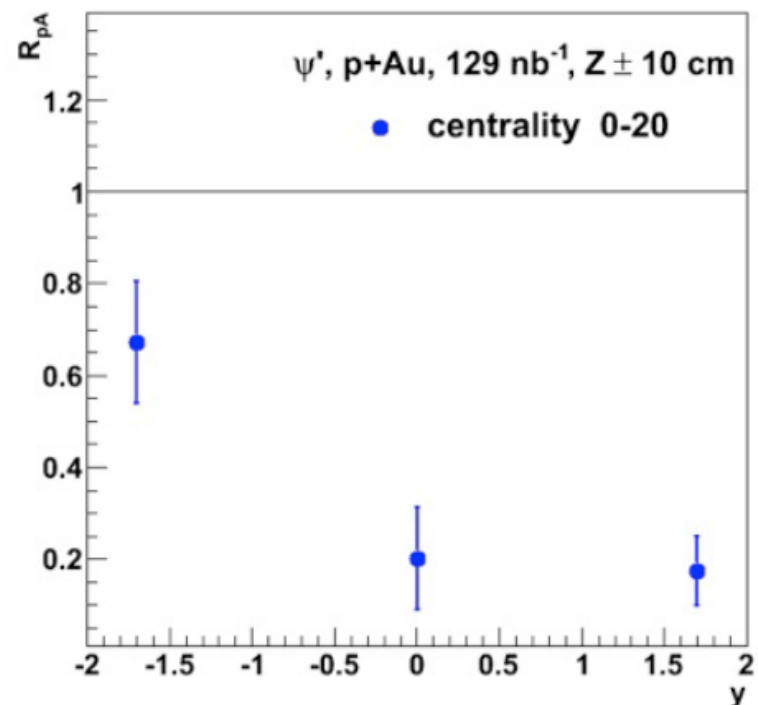
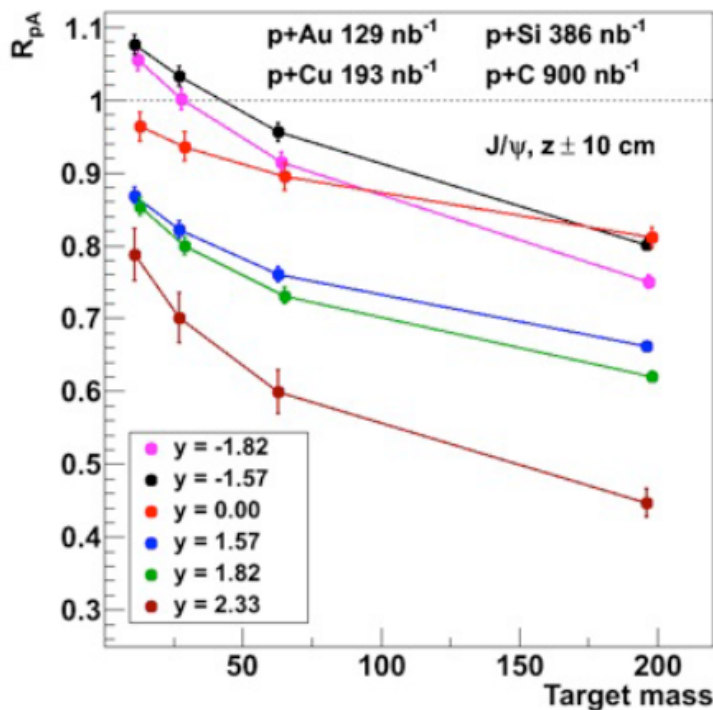
- PHENIX has a first $J/\psi:\psi'$ result at forward rapidity from p+p 510 GeV
- FVTX detector allows separation of J/ψ and ψ'
- Heavy Ion analysis underway. p+A data set coming.



pA Projections for Quarkonia

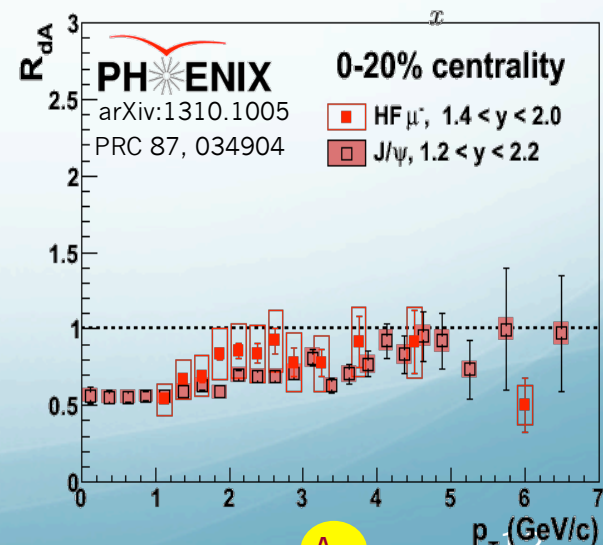
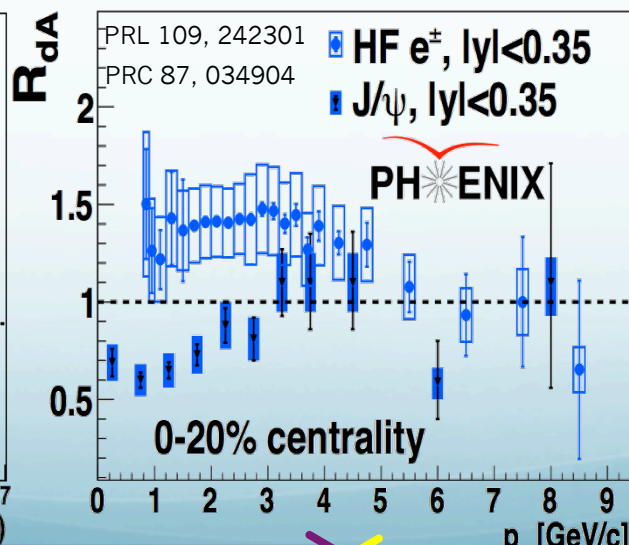
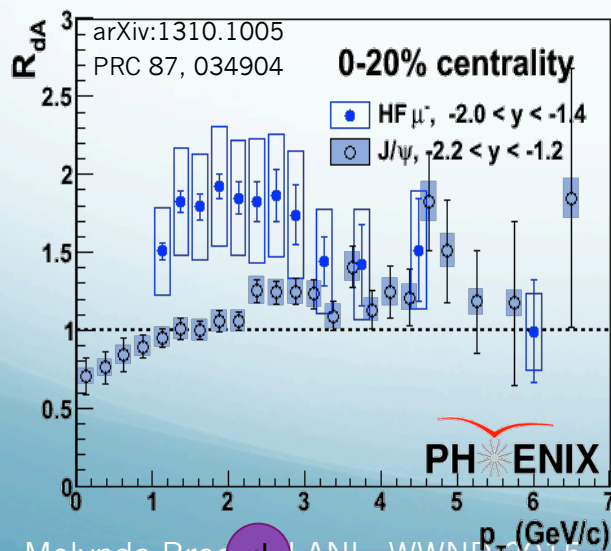
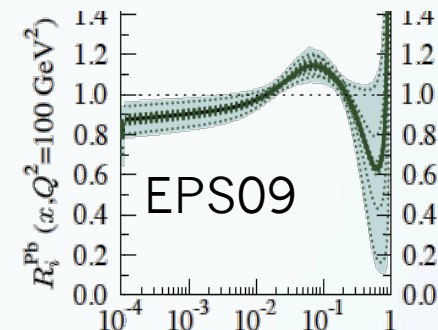
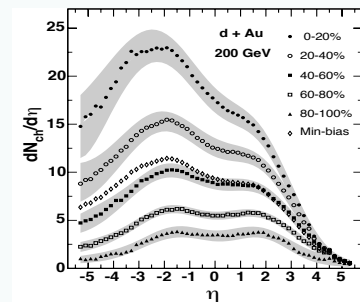
- Expect J/ψ measurements of significance for several nuclei
- p+Au will provide a good statistical measurement of ψ'

p+A projections for Run 15



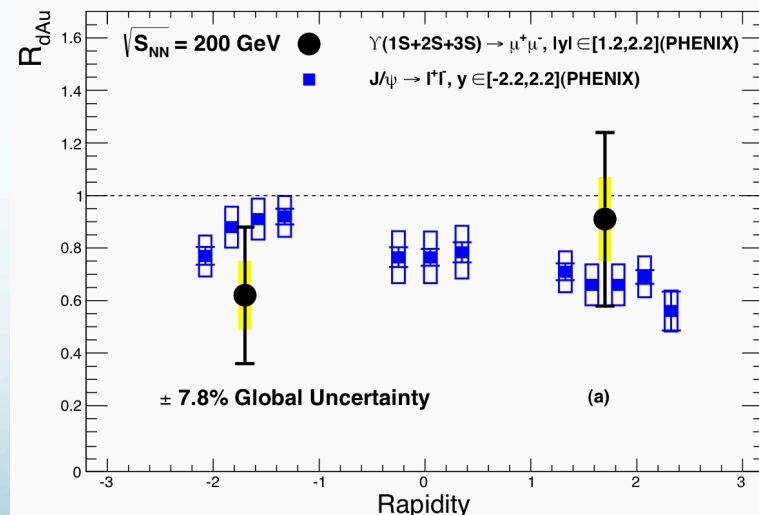
CNM for Open and Closed Heavy Flavor

- Open heavy flavor shows a different rapidity dependence from J/ψ
- Combination of initial-state and final-state effects or primarily final-state?
- The FVTX will allow more precise measurement to better quantify differences from Run 15 p+A



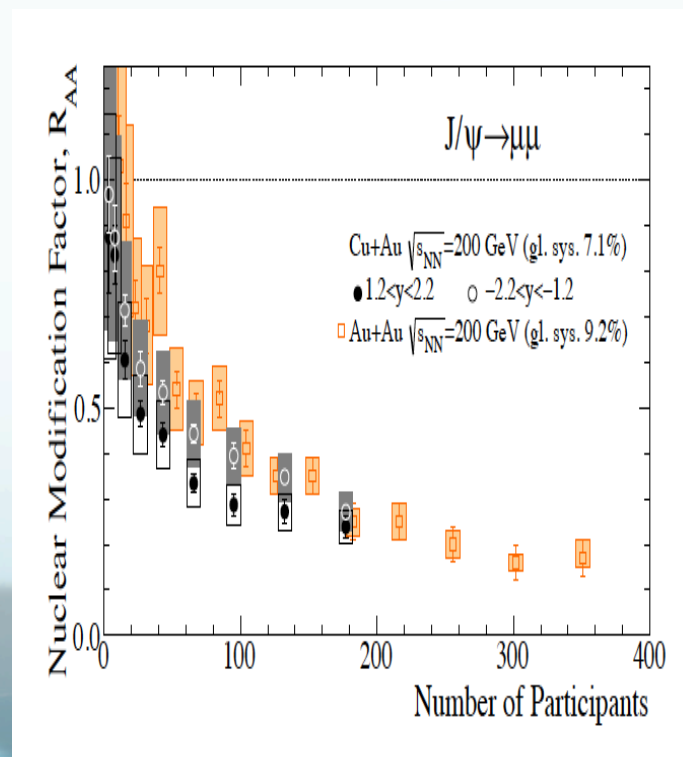
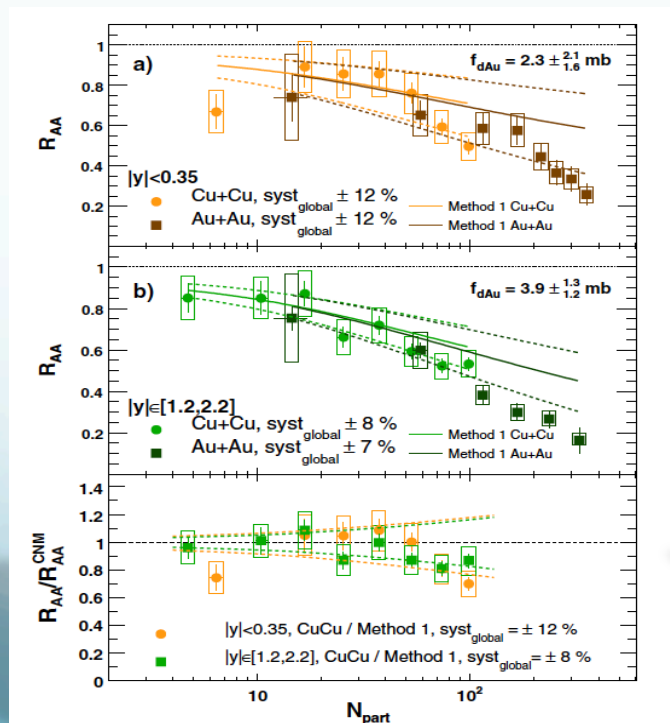
What About Upsilons?

- Possible suppression at *backward* rapidity (but error bars large)
- Forward rapidity may or may not be suppressed
- Challenging to make significantly better measurements with PHENIX. sPHENIX proposes to continue upsilon program.



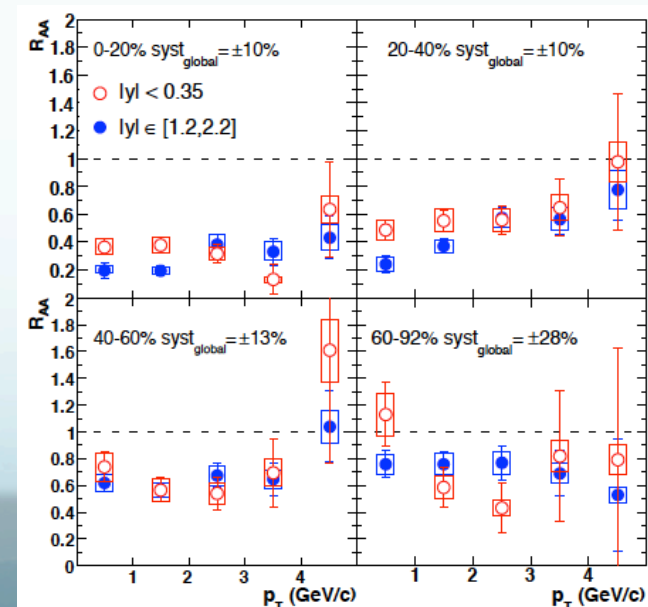
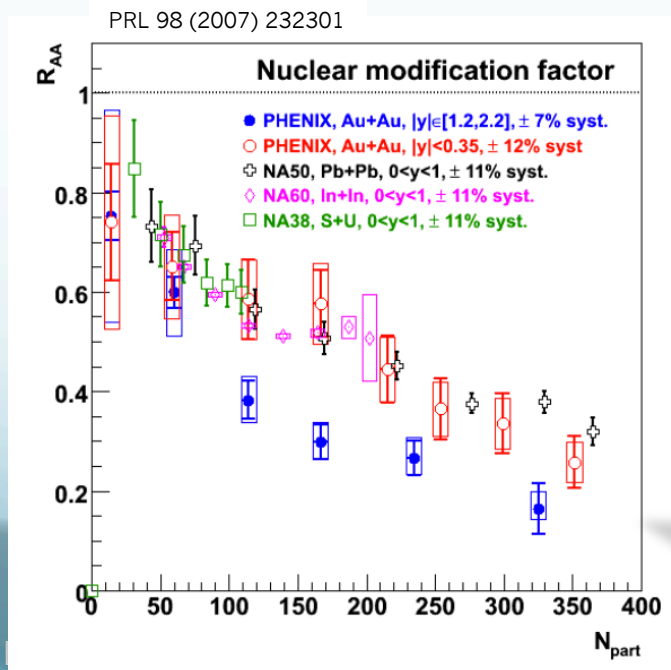
System Size and CNM

- Suppression similar for smaller systems (CuCu) and larger (AuAu). Close to value extrapolated from dAu (modified PDF and breakup)
- Small rapidity dependence in CuAu, more consistent with CNM effects than QGP



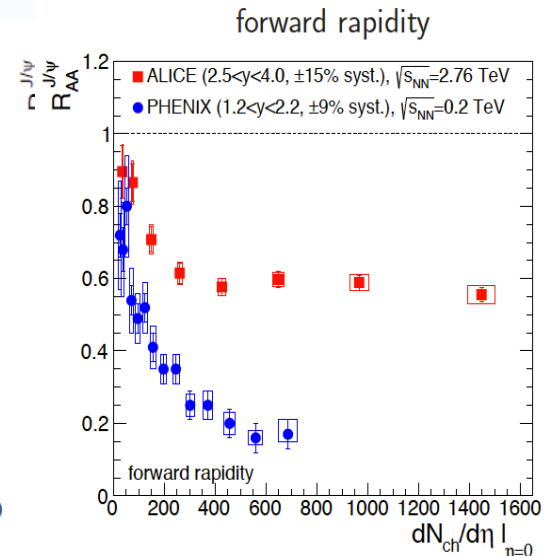
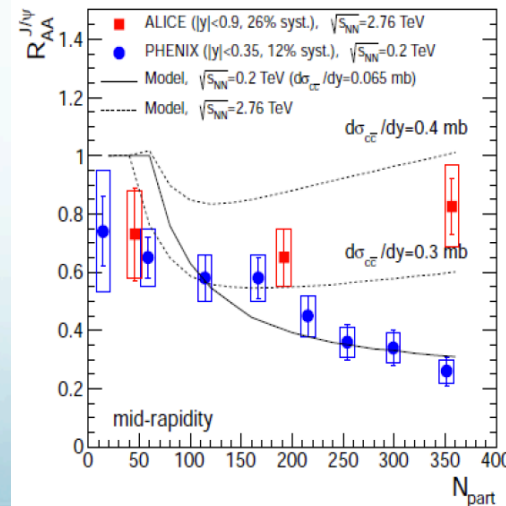
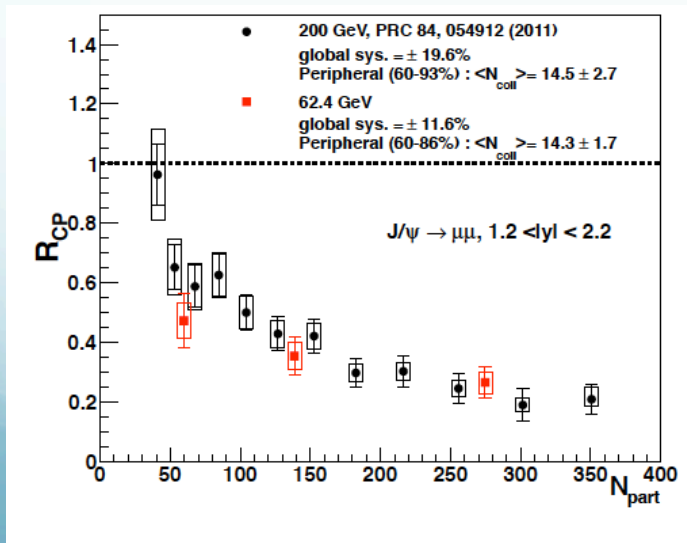
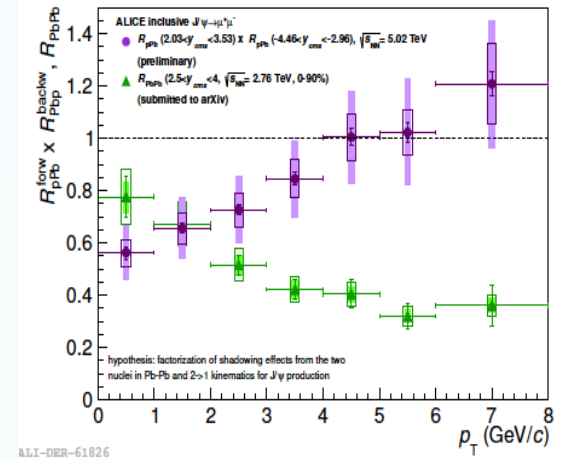
J/ ψ Heavy Ion Measurements

- J/ ψ suppression strikingly similar at SPS and RHIC despite different energies
- Rapidity dependence not initially expected: CNM effects bring forward down? Coalescence brings central up?
- p_T dependence does not show a strong effect



Energy Dependence Cont'd

- Explore energy dependence more at RHIC
- Don't see large change in suppression until LHC
- p_T dependence now looks consistent with coalescence picture



Heavy Ion $\psi':J/\psi$

- At LHC energies, the $J/\psi:\psi'$ ratio also seems to now deviate from linear trend.
- Another indication of coalescence at LHC? What will we see in RHIC heavy ion?

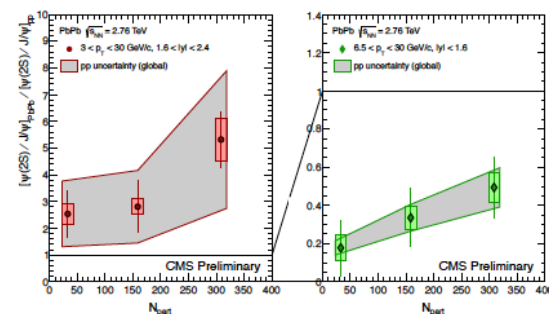
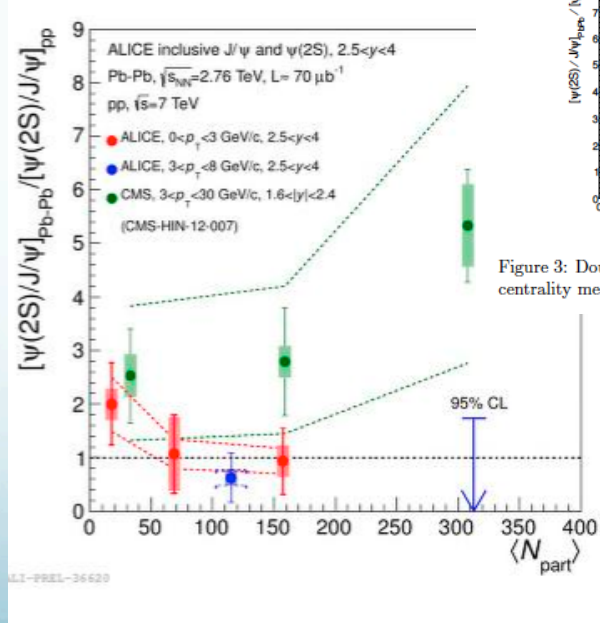
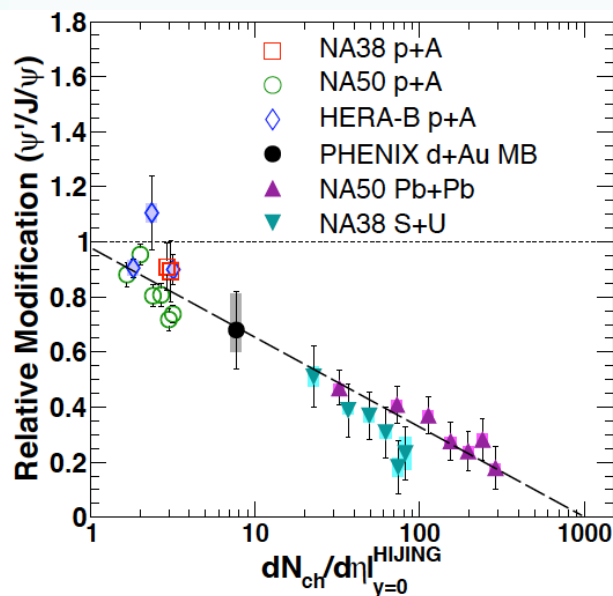
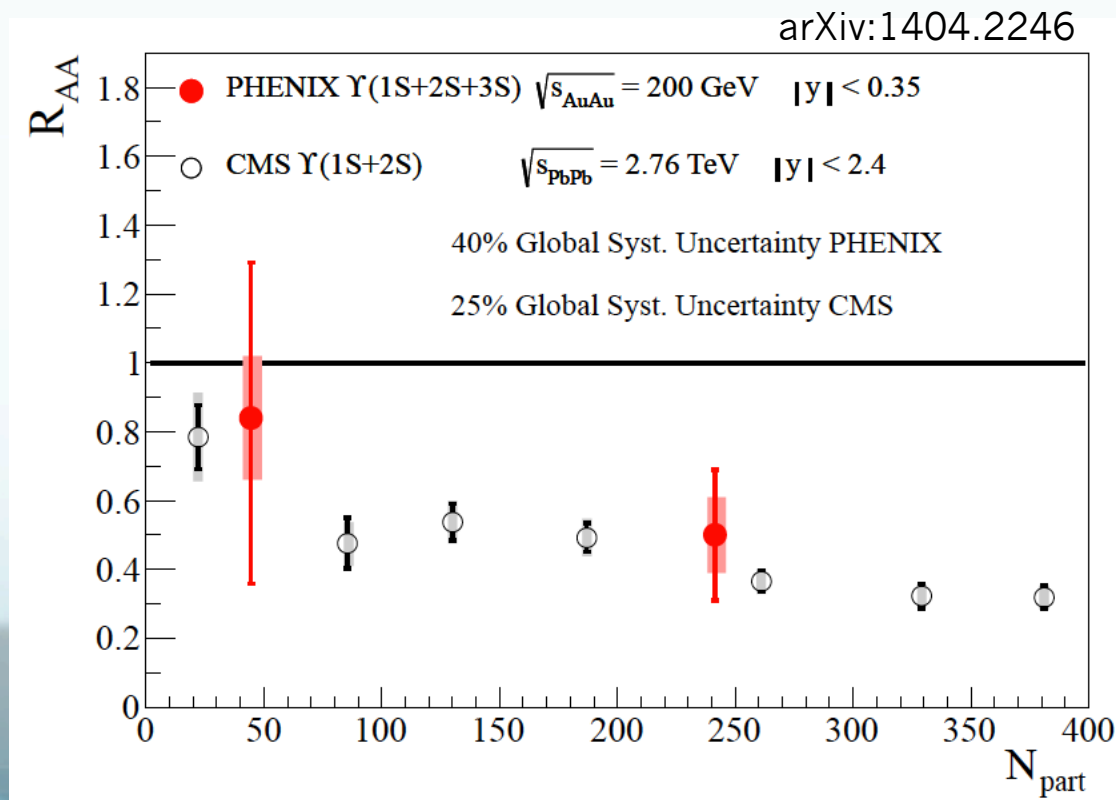


Figure 3: Double ratio (ratio of ratios in PbPb to pp) of $\psi(2S)$ and J/ψ as a function of centrality measured by CMS in two kinematic regions [19].

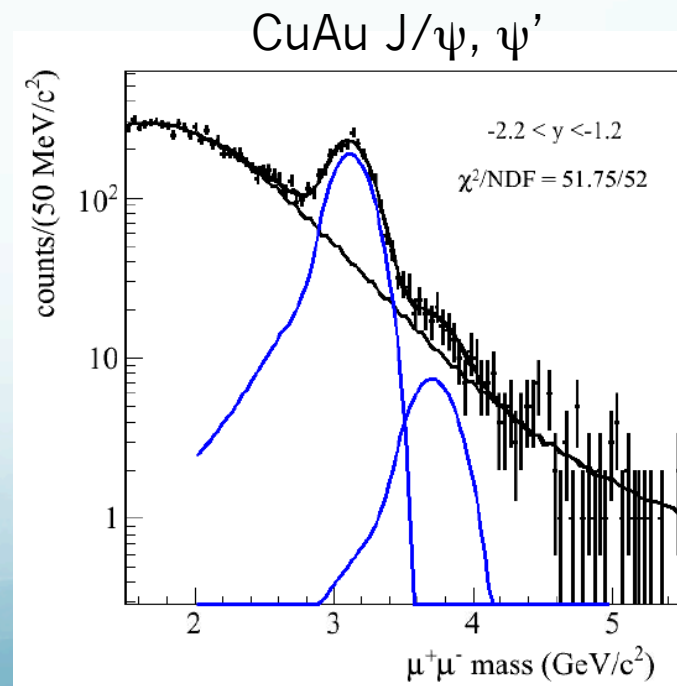
Upsilon Au-Au

- $R_{AA} \sim 0.65$ if no 2S, 3S
- $R_{AA} \sim 0.37$ if no 2S, 3S, χ_B
- PHENIX consistent with 2S, 3S states both melt, if no other suppression effects



What's Next at PHENIX?

- $J/\psi:\psi'$ ratio in CuAu and AuAu at forward rapidity – will we see any ψ' ?
- $J/\psi:\psi'$ ratio in p+A at forward and backward rapidity – will it follow same $dN_{ch}/d\eta$ trend?
- $J/\psi:\psi'$ ratio versus multiplicity
- Higher precision open heavy flavor, B/D separation



Summary

- Significant suppression of J/ψ in d-Au; x_2 dependence → suppression not from gluon shadowing
- Extrapolation to heavy ion similar to what is measured except perhaps central AuAu → what might QGP suppression be? Can we reduce extrapolation errors?
- ψ' suppressed beyond J/ψ in d+Au, proportional to $dN_{ch}/d\eta$ independent of energy → co-mover type effect, not nuclear medium?
- J/ψ suppression in heavy ion: similar N_{part} trend across energies, system-size until LHC where suppression is reduced → recombination?
- How much of J/ψ suppression might be due to QGP effects? Does ψ' survive in heavy ion collisions at RHIC?